Simultaneous recording of auditory-evoked brain potentials and continuous, high-field functional magnetic resonance imaging in humans

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INTRODUCTION

Simultaneous recording of EEG and fMRI responses is especially important when the brain activity of interest is not easily reproducible in separate sessions. It allows direct single-trial comparison of human brain responses to an external stimulus with complementary spatial and temporal resolution. Besides the well-known technical difficulties of truly simultaneous EEG/fMRI recording, the loud acoustic noise generated during fMRI creates a potential confound for the recording of auditory evoked potentials, with conflicting effects reported on auditory brain activation (Cho et al., 1998; Novitsky et al., 2001). To avoid this problem, previous EEG/fMRI studies have interleaved the fMRI acquisition with the recording of AEPs, allowing the stimuli to be delivering in 'quiet' periods (Liebenthal et al., 2003; Scarff et al., 2004). However, interleaving EEG and fMRI has important practical and theoretical limitations, including inefficient sampling of the neural activity and the consequent haemodynamic response, and a reduction in the flexibility of the stimulus presentation paradigm. In this study we investigated the feasibility of recording AEPs during simultaneous and truly continuous collection of blood oxygen level-dependent (BOLD) fMRI at 3T.

DATA ACQUISITION

7 healthy volunteers (1 female), mean age ±SD (29.5±2.4 years) participated in this study. All subjects gave informed consent and the local ethics committee approved the procedures. For each subject, AEPs were recorded in two sessions conducted on the same day. In the fMRI session, EPs were recorded during continuous fMRI at 3T. In the Control session, EPs were recorded in the magnet bore but without fMRI acquisition. 1kHz electronic pure tones were delivered via pneumatic tubing to passive ER-30 earphones (http://www.etymotic.com/) inserted inside the ear and mounted inside ear defenders which reduced MRI noise by 30dB. Auditory stimuli were presented at 0.4Hz in a block design, with 30 seconds of stimulation (12 stimuli) followed by 30 seconds of silence. The sound pressure level of the stimulus presentation was kept constant across subjects. All subjects reported after the experiment that they had heard the stimuli without difficulties. The EEG recording was identical during both sessions. Electroencephalogram was recorded with 30 electrodes using an EASYCAP according to the 10-20 system, with the nose as a common reference. Electrode impedance was kept below 5kΩ. In order to discard trials contaminated by eye-blinks, electroculographic (EOG) signals were recorded from surface electrodes. In order to subtract the ballisto-cardiographic (BCG) pulse artefact, the electrocardiogram (ECG) was also recorded during both sessions. EEG data was digitized with an MR-compatible, 22-bit, 32-channel amplifier (SD-MRI, Micromed, Italy) bandwidth 0.15-600Hz, sampling rate 2048Hz. Continuous whole-brain T2* weighted, gradient-echo EPI sequence was used for the functional scans (TR = 3s, TE = 30 ms, 43 contiguous 3-mm-thick axial slices, image matrix 64 x 64, flip angle 90º) over 184 volumes, corresponding to a total scan time of 9 minutes.

DATA ANALYSIS

EEG data were imported and analysed using EEGLAB (www.sccn.ucsd.edu/eeglab) (Delorme and Makeig., 2004). MRI gradient and BCG pulse artifacts present in the EEG data from the fMRI session were removed using the FASTR and OBS algorithms respectively (Niazy et al., 2006). Continuous EEG data was down-sampled to 256Hz and band-pass filtered from 0.5-40 Hz. EEG epochs containing the auditory stimuli were extracted using a window of 2s (from 1000 ms pre-stimulus to 1000 ms post stimulus). For each epoch a baseline correction for the pre-stimulus data was performed. EEG recordings were manually inspected and trials contaminated with eye-blinks or gross movements were rejected. An ICA decomposition using the infomax algorithm (Bell and Sejnowski., 1995) was performed and components that correlated with the ECG signal were rejected as residual BCG artefacts. fMRI Analysis was carried out using FEAT (FMRI Expert Analysis Tool) Version 5.64, part of FSL (FMRIB's Software Library, www.fmrib.ox.ac.uk/fsl). Time-series statistical analysis was carried out using FILM with local autocorrelation correction. Z (Gaussianised T/F) statistic images were thresholded using clusters determined by Z>2.3 and a (corrected) cluster significance threshold of P=0.05. Registration to high resolution and/or standard images was carried out using FLIRT. A fixed-effects group analysis was performed and z-statistic maps for auditory activation computed.

RESULTS

Group mean AEP waveforms and scalp maps during fMRI and control sessions (Fig. 1). On the grand mean of both sessions, the earliest identifiable response was the negative component (N1) component peaking at approximately 110ms, followed by the positive component (P2) peaking at approximately 250ms. Scalp maps show a strong centrally-distributed response for both N1 and P2 components in both fMRI and control sessions. BOLD map shows robust activation in the auditory cortex (Fig. 2.).

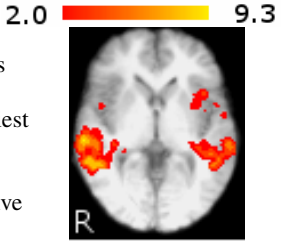

Fig. 2. Group auditory evoked brain responses

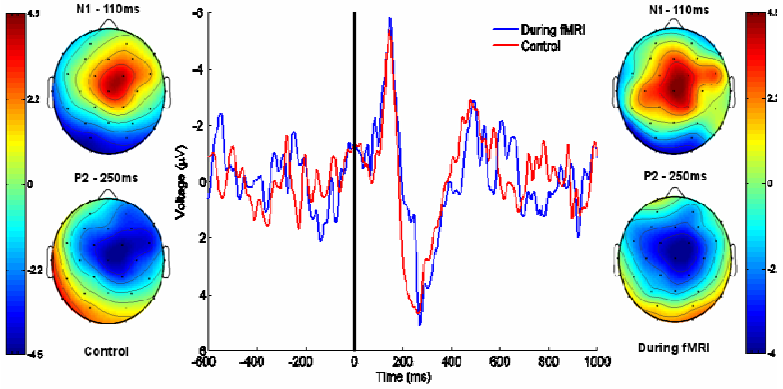

Fig. 1. Grand mean AEP waveforms and scalp maps recorded during: fMRI imaging (blue); Control session (inside scanner, no fMRI, red). Left scalp maps acquired during control. Right scalp maps acquired during fMRI

DISCUSSION AND CONCLUSIONS

Our results demonstrate the feasibility of simultaneously recording reliable AEPs with continuous fMRI at 3T, and indicate that the MRI background noise does not interfere significantly with the AEP generation. This allows avoiding the theoretical and practical limitations of interleaved experimental designs when investigating the auditory system with simultaneous EEG and fMRI.

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